

WHAT IS CLAIMED IS:

5 1. A three-dimensional steering tool for use in  
drilling a borehole in an underground formation in which an  
elongated conduit extends from the surface through the  
borehole and in which the steering tool is mounted on the  
conduit near a drill bit for drilling the borehole, the  
10 steering tool comprising an integrated telemetry section,  
rotary section and flex section aligned axially along the  
steering tool for separately controlling inclination and  
azimuth angles at the drill bit; in which the flex section  
includes an elongated drive shaft coupled to the drill bit and  
15 adapted to be rotatably driven for rotating the drill bit, the  
drive shaft being bendable laterally to define a deflection  
angle thereof, and a deflection actuator coupled to the drive  
shaft, the deflection actuator comprising a deflection housing  
surrounding the drive shaft and having a longitudinal axis and  
20 an elongated deflection piston movable in the deflection  
housing for applying a lateral bending force to the drive  
shaft for making changes in the deflection angle of the drive  
shaft which is transmitted to the drill bit as an inclination  
angle steering adjustment; in which the rotary section is  
25 coupled to the actuator and includes a rotator actuator for  
transmitting a rotational force to the deflection actuator to  
rotate the deflection piston to thereby change the rotational  
angle at which the lateral bending force is applied to the  
drive shaft which is transmitted to the drill bit as an  
30 azimuth angle steering adjustment; and in which the telemetry  
section measures the inclination angle and the azimuth angle  
during drilling and compares them with desired inclination and  
azimuth angle information to produce inclination control  
signals for operating the deflection actuator to make steering

adjustments in the inclination angle and for separately  
producing azimuth control signals for operating the rotator  
5        actuator for making steering adjustments in the azimuth angle.

2.        Apparatus according to claim 1 in which the conduit  
is an elongated rotary drill string.

10        3.        Apparatus according to claim 1 in which the  
deflection actuator comprises an elongated deflection housing  
surrounding the drive shaft, and an elongated hydraulically  
operated piston in the deflection housing for applying the  
bending force distributed lengthwise along the drive shaft for  
15        flexing the drive shaft laterally to produce said deflection  
angle thereof to thereby change the inclination angle at the  
drill bit.

20        4.        Apparatus according to claim 3 in which the rotator  
actuator is coupled to the deflection housing and includes a  
rotator piston movable in proportion to a desired change in  
the azimuth angle and a helical gear arrangement on the  
deflection housing coupled to the rotator piston and rotatable  
in response to piston travel to rotate the deflection housing  
25        to change the azimuth angle at the drill bit.

30        5.        Apparatus according to claim 1 in which the  
hydraulically powered bending force is applied to the  
deflection piston by drilling mud taken from an annulus  
between the conduit and the borehole.

35        6.        Apparatus according to claim 1 in which the  
deflection actuator applies the bending force to the drive  
shaft while the rotary actuator applies the rotational force

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to the deflection actuator for making simultaneous adjustments  
in the inclination angles and the azimuth angles.

5           7. Apparatus according to claim 1 in which the feedback  
loop comprises a closed loop controller including a comparator  
for receiving the measured and desired inclination angle and  
azimuth angle command signals for producing inclination and  
10 azimuth error signals for making the steering adjustments.

8. Apparatus according to claim 1 in which the  
telemetry section comprises an onboard mud pulse telemetry  
section for receiving the desired inclination and azimuth  
15 angle input signals and utilizing mud pulse controls for  
operating the deflection actuator and the rotator actuator  
from drilling mud taken from an annulus between the conduit  
and the borehole.

20       9. The apparatus according to claim 8 in which the mud  
pulse telemetry section provides open loop control to the  
deflection actuator and the rotator actuator, and in which  
electrical controls provide closed loop control to the  
actuators.

25       10. Apparatus according to claim 1 in which the  
deflection actuator includes axially spaced-apart end bearings  
for mounting the drive shaft along a longitudinal axis of the  
steering tool, and a deflection piston for applying the  
30 lateral bending force to the drive shaft between the end  
bearings to bend the drive shaft while the end bearings  
constrain the drive shaft on opposite sides of the deflection  
piston.

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5        11. Apparatus according to claim 1 in which the  
deflection piston contained in the deflection housing is  
positioned on one side of the drive shaft and the drive shaft  
has a longitudinal axis aligned with a longitudinal axis of  
the deflection housing, and the lateral bending force is  
applied by the piston as a unitary force which physically  
bends the drive shaft to deflect its longitudinal axis away  
10       from the axis of the deflection housing.

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